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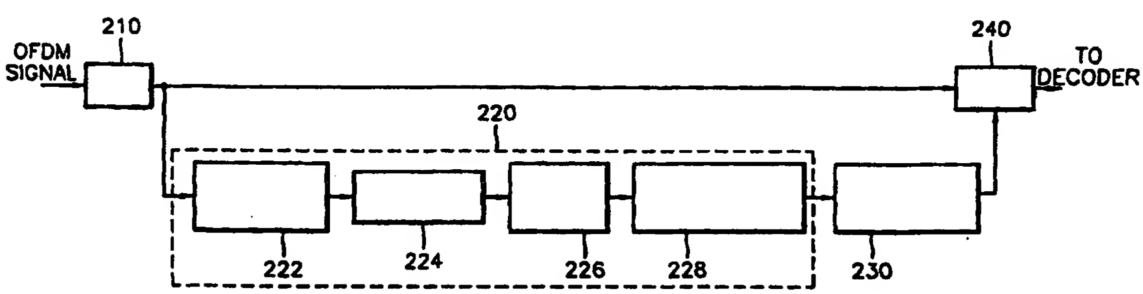

(57) Abstract

A fast Fourier transform (FFT) window position recovery apparatus in an orthogonal frequency division multiplexing (OFDM) receiver is provided. In the FFT window position recovery apparatus in an OFDM system receiver which receives an OFDM symbol comprised of N effective data samples and G guard intervals and recovers a FFT window position, the apparatus includes an analog–to–digital converter (ADC) (210) for converting a received OFDM signal into a digital complex sample, a symbol start detector (220) for quantizing a phase difference between the adjacent digital complex samples output by the ADC and detecting a position having a maximum correlation value with respect to the quantized values, as a symbol starting position, and a FFT window controller (230) for activating FFT using symbol start information detected by the symbol start detector. The influence of a frequency offset is reduced by using the phase difference between adjacent samples, thus improving the reliability of a system. Also, bit operation can be performed by using 3–bit quantization, thus simplifying the system.

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FAST FOURIER TRANSFORM WINDOW POSITION RECOVERY APPARATUS FOR ORTHOGONAL FREQUENCY DIVISION MULTIPLEXING SYSTEM RECEIVER

Technical Field

The present invention relates to an orthogonal frequency division multiplexing (OFDM) system, and particularly to a fast Fourier transform (FFT) window position recovery apparatus in an OFDM receiver.

Background Art

In general, time synchronization must be accurately performed to allow a receiver to recover a European digital broadcast OFDM signal transmitted from a transmitter. Time synchronization is comprised of FFT window position recovery for accurate parallel processing of a signal, and sampling clock recovery for controlling a sampling clock of an analog-to-digital converter (ADC) for sampling a signal having a maximum signal-to-noise ratio (SNR) among received signals.

FIG. 1 is a block diagram showing the configuration of a general OFDM system receiver, and FIG. 2 is a block diagram of the symbol start detector 120 of FIG. 1. First, when the number of bins of FFT is N, a symbol of an OFDM signal comprises N effective data samples output by inverse fast Fourier transform (IFFT) for transmission and a guard interval having the lengths of G samples interposed between symbols to prevent interference between the symbols. That is, a transmitter (not shown) copies the end portion of an effective section. Then, the transmitter adds the copied result to N complex values output by an inverse fast Fourier transformer (IFFT: not shown), and sequentially transmits a symbol comprised of a total of (G+N) samples.

$$s_j = \sum_{n=-G}^{N-1} x_{j,n} = \sum_{n=-G}^{-1} \sum_{k=0}^{N-1} X_{j,k} e^{j2\pi(N+n)/N} + \sum_{n=0}^{N-1} \sum_{k=0}^{N-1} X_{j,k} e^{j2\pi kn/N} \qquad \ldots(1)$$

wherein j denotes a symbol number, k is a carrier index (number), N is the number of effective data samples, n indicates a sampling time, and X(•) and

x(•) respectively denote an input complex value and an output complex value of the transmission IFFT. Equation 1 shows a j-th symbol comprised of complex values output by a fast Fourier transformer (FFT) 140. In the right side of Equation 1, the first term is a guard interval portion and the second term is an effective data portion.

As shown in FIG. 1, an analog-to-digital converter (ADC) 110 samples a received OFDM signal and converts the sampled OFDM signal into digital data. A symbol start detector 120 detects a start portion of a symbol from the sampled OFDM data output by the ADC 110. A FFT window controller 130 designates a point in time to activate a FFT 140 using the symbol start portion detected by the symbol start detector 120. Here, a value output from the first end of an IFFT (not shown) of a transmitter must be input to the first end of the FFT 140 of a receiver, and a value output by the N-th end of the IFFT must be input to the N-th end of the FFT 140. However, an accurate symbol starting portion may not be estimated by a fading phenomenon or an environmental effect upon movement of the receiver, so that the symbol start detector 120 misjudges the symbol starting portion. In the prior art, this symbol start portion is detected either by finding a maximum position of a correlation value between received signals or by finding a minimum position of an absolute value of the difference between the received signals. However, these two ways require a correlation value therebetween, resulting in complicated system realization. Alternatively, the symbol starting position can be detected by using 2-bit quantization of an input signal. This way provides a simple structure because of the 2-bit quantization. However, when a frequency offset defined as a carrier frequency synchronization fault exists, phase rotation of the input signal occurs to thus change the phases of an effective section end portion and a guard interval. Thus, a position having a maximum correlation value cannot be found, and symbol starting position recovery is difficult.

Disclosure of the Invention

It is an object of the present invention to provide a FFT window

position recovery apparatus for quantizing a phase difference between received adjacent complex sample values and recovering a phase fault of a fast Fourier transform (FFT) window using a position having a maximum correlation value with respect to the quantized values in an orthogonal frequency division multiplexer (OFDM) system.

To accomplish the above object, there is provided a fast Fourier transform (FFT) window position recovery apparatus in an orthogonal frequency division multiplexing (OFDM) system receiver which receives an OFDM symbol comprised of N effective data samples and G guard intervals and recovers a FFT window position, the apparatus comprising: an analog-to-digital converter (ADC) for converting a received OFDM signal into a digital complex sample; a symbol start detector for quantizing a phase difference between the adjacent digital complex samples output by the ADC and detecting a position having a maximum correlation value with respect to the quantized values, as a symbol starting position; and a FFT window controller for activating FFT using symbol start information detected by the symbol start detector.

Brief Description of the Drawings

FIG. 1 is a block diagram showing the configuration of a general orthogonal frequency division multiplexing (OFDM) system receiver;

FIG. 2 is a block diagram of a fast Fourier transform (FFT) window position recovery apparatus in an OFDM system receiver according to the present invention;

FIG. 3 is a block diagram of the phase difference detector of FIG. 2;

FIG. 4 is a constellation diagram of the phase of an input signal quantized to 3 bits;

FIG. 5 is a block diagram of the correlator of FIG. 2; and

FIG. 6 is a concept view for FFT window position search.

Best mode for carrying out the Invention

Referring to FIG. 2, a FFT window position recovery apparatus in an

OFDM system receiver according to the present invention is comprised of an analog-to-digital converter (ADC) 210, a starting position detector 220, a FFT window position controller 230, and a fast Fourier transformer (FFT) 240. Here, the starting position detector 220 includes a phase difference detector 222, a correlator 224, a slide window adder 226, and a maximum value position detector 228.

As shown in FIG. 2, an input OFDM signal is sampled and converted into digital data as expressed in Equation 2 by the ADC 210:

$$\gamma(k) = \gamma(t), \; t = kT \qquad ...(2)$$

wherein $\gamma(k)$ is a sampled complex signal, $\gamma(t)$ is a received OFDM signal, k is 0, 1, 2,..., and T is a rated sampling cycle.

The symbol start detector 220 quantizes a phase difference between digital complex samples output by the ADC 210, and detects a position having a maximum correlation value with respect to the quantized values, as a symbol starting portion.

That is, the phase difference detector 222 receives a complex signal $\gamma(k)$ output by the ADC 210 and detects a phase difference between adjacent samples (i.e., between k-th sample and (k−1)th sample). FIG. 3 is a block diagram of the phase difference detector of FIG. 2, including a quantizer 310, a delay 320, a phase difference operator 330, and an adjuster 340. As shown in FIG. 3, the quantizer 310 converts the phase of the complex signal $\gamma(k)$ into 3-bit quantized data C(k). Here, 2-bit quantization is not properly performed under poor noise environments, and quantization of more than 3 bits increases the capacity for storing data and the amount of operation calculation. Thus, 3 bits are selected for optimal quantization. As shown in FIG. 4, the phase of the received complex signal $\gamma(k)$ is divided into eight regions as different values by the quantizer 310. These values can be expressed in 3 bits. For example, the phases of i-th, (i+1)th, and (i+2)th signals are quantized to Q1, Q2 and Q3, respectively. These quantized values Q0, Q1, Q2, Q3, Q4,... are expressed, respectively, as 0, 1, 2, 3, 4,..., as shown in Equation 3:

$$\{Q0, Q1, Q2, Q3, Q4, Q5, Q6, Q7\} = \{0, 1, 2, 3, 4, 5, 6, 7\} \qquad ...(3)$$

The quantizer 310 outputs a representative value of a region to which the phase position of an input complex signal pertains, as shown in Equation 4:

$$c(k) = Q[\gamma(k)],\ k = 1, \ldots\ldots\ldots\ 2N+G \qquad \ldots(4)$$

wherein $Q[\gamma(k)]$ is a function for outputting a quantized sample value $c(k)$ with respect to the sampled input complex signal $\gamma(k)$. Here, when a frequency offset exists, the phase of a complex signal in the guard interval is no longer consistent with that in the rear effective section, which makes it impossible to use the quantized value output by the quantizer 310 without change. Accordingly, in order to reduce the influence of the frequency offset, a phase difference between adjacent samples $c(k)$ and $c(k-1)$ is obtained by applying a differential encoding process. The sample value $c(k)$ output by the quantizer 310, and the one-sample-delayed sample value $c(k-1)$ by the delay 320 are operated by the phase difference operator 330 to output phase difference data $d(k)$ as expressed by Equation 5. Also, the phase difference data $d(k)$ has 15 values by the operations on 3-bit quantized values as expressed by the following Equation 5:

$$d(k) = c(k)-c(k-1) \qquad \ldots(5)$$

The phase difference data $d(k)$ value is adjusted to a phase change value to only the same direction by the adjuster 340. The following Equation 6 is for adjusting the phase difference data value to a value of a phase change to only the same direction for convenience of calculation of the correlation value:

$$d(k)<0:d(k) = d(k) + 8$$
$$d(k)\geq 0:d(k) = d(k) \qquad \ldots(6)$$

For example, when $c(k)$ is 0, $c(k+1)$ is 4, $c(k+2)$ is 1, and $c(k+3)$ is 6, $d(k+1)$ is 4, $d(k+2)$ is -3, and $d(k+3)$ is -5. Here, (−) code denotes a clockwise change in phase, and (+) code denotes a counterclockwise change in phase, so Equation 6 expresses a phase change to only the same direction.

Next, in order to obtain the correlation value between the guard interval (G) and the rear effective section, the correlator 224 calculates the

correlation value between the phase difference data d(k) and N-delayed phase difference data output by the adjuster 340.

FIG. 5 is a block diagram of the correlator 224 of FIG. 2. A correlation operator 520 obtains the correlation between the phase difference data d(k) and the N-sample-delayed phase difference data d(k−N) by the delay 510. That is, as shown in FIG. 6, a first block BLOCK1 is a value stored from an arbitrary position (0) to a symbol length (N+G), and a second block BLOCK2 is a value stored from the start point in time N to a symbol length (2N+G). A guard interval (G) in the first block BLOCK1 is N-sample delayed from the storing position by the delay 510, thus being in the same location as a rear effective data section (G') in the second block BLOCK2 having the same data as the guard interval (G). In the correlation between the first and second blocks BLOCK1 and BLOCK2, the sections G and G' are the most closely correlated with each other because they have the same data. The residual sections are hardly correlated with each other because they have arbitrary data. A look-up table of a correlation value with respect to a 3-bit quantized value is used to simplify the structure of the correlator 224. That is, in a look-up table (Table 1), a weighted value varies according to the values between the phase difference data d(k) and d(k−N) being input values. That is, when a k-th signal is Q0 and a (k−N)th signal is also Q0, an arbitrary correlation value of 2 is given. When the k-th signal is Q0 and the (k−N)th signal is Q4, a least correlated value of −2 is given.

The slide window adder 226 adds the correlation values output by the correlator 224 within the guard interval (G). The slide window adder 226 performs addition while moving a window from the start point in time 0 to a point in time N in units of one sample. As shown in FIG. 6, the output value of the slide window adder 226 is maximum at a symbol start point in time (i). The maximum value position detector 228 considers this arbitrary point in time as a maximum value and detects this point in time as the symbol starting point. Accordingly, the maximum value position detector 228 detects the maximum value from the summed correlation value and sets the detected maximum value to be a FFT window moving value.

The FFT window position controller 230 designates the position where fast Fourier transform (FFT) is activated by the FFT 240, including a symbol staring position, using position information of the maximum value detected by the maximum value position detector 228. The FFT 240 fast-Fourier-transforms data generated by the ADC 210 according to a FFT window position control signal generated by the FFT window position controller 230.

<Table 1>

		d(k)							
		Q0	Q1	Q2	Q3	Q4	Q5	Q6	Q7
d(k−N)	Q0	2	1	0	−1	−2	−1	0	1
	Q1	1	2	1	0	−1	−2	−1	0
	Q2	0	1	2	1	0	−1	−2	−1
	Q3	−1	0	1	2	1	0	−1	−2
	Q4	−2	−1	0	1	2	1	0	−1
	Q5	−1	−2	−1	0	1	2	1	0
	Q6	0	−1	−2	−1	0	1	2	1
	Q7	1	0	−1	−2	−1	0	1	2

<u>Industrial Applicability</u>

According to the present invention as described above, the influence of a frequency offset is reduced by using the phase difference between adjacent samples, thus improving the reliability of a system. Also, bit operation can be performed by using 3-bit quantization, thus simplifying the system.

A Fourier transform window position recovery apparatus accoring to the present invention is applied in an orthogonal frequency division multiplexing system.

What is claimed is:

1. A fast Fourier transform (FFT) window position recovery apparatus in an orthogonal frequency division multiplexing (OFDM) system receiver which receives an OFDM symbol comprised of N effective data samples and G guard intervals and recovers a FFT window position, the apparatus comprising:

an analog-to-digital converter (ADC) 210 for converting a received OFDM signal into a digital complex sample;

a symbol start detector 220 for quantizing a phase difference between the digital complex samples output by the ADC and detecting a position having a maximum correlation value with respect to the quantized values, as a symbol starting position; and

a FFT window controller 230 for activating FFT using symbol start information detected by the symbol start detector.

2. The FFT window position recovery apparatus in an OFDM system receiver as claimed in claim 1, wherein the symbol start detector comprises:

a phase difference detector 222 for quantizing the phases of the digital complex samples output by the ADC and detecting a phase difference between successive adjacent samples;

a correlator 224 for calculating a correlation value between the phase difference output by the phase difference detector and a phase difference delayed by intervals of N samples;

a slide window adder 226 for adding the correlation values output by the correlator while the correlation values move by every sample during the guard interval period; and

a maximum value position detector 228 for detecting a maximum value among the output values of the slide window adder.

3. The FFT window position recovery apparatus in an OFDM system receiver as claimed in claim 2, wherein the correlator comprises a

look-up table 520 for providing different weighted values in proportion to the difference between two sample values.

4. The FFT window position recovery apparatus in an OFDM system receiver as claimed in claim 2, wherein the phase difference detector comprises:

a quantizer 310 for quantizing the phases of the digital complex samples output by the ADC;

a phase difference operator 330 for operating a phase difference between successive adjacent samples from the samples output by the quantizer; and

an adjuster 340 for adjusting the phase difference output by the phase difference detector to be a one-directional level.

5. The FFT window position recovery apparatus in an OFDM system receiver as claimed in claim 4, wherein the phase difference operator comprises:

a delay 320 for delaying by one sample a quantized value c(k) output by the quantizer; and

a phase difference operator 330 for adding the c(k) to a quantized value c(k−1) delayed by one sample.

6. The FFT window position recovery apparatus in an OFDM system receiver as claimed in claim 4, wherein the quantizer is a 3-bit quantizer.

7. The FFT window position recovery apparatus in an OFDM system receiver as claimed in claim 4, wherein the phase difference is adjusted by the adjuster as follows:

$d(k)<0:d(k) = d(k)+8$

$d(k)\geq 0:d(k) = d(k)$.

FIG. 1 (PRIOR ART)

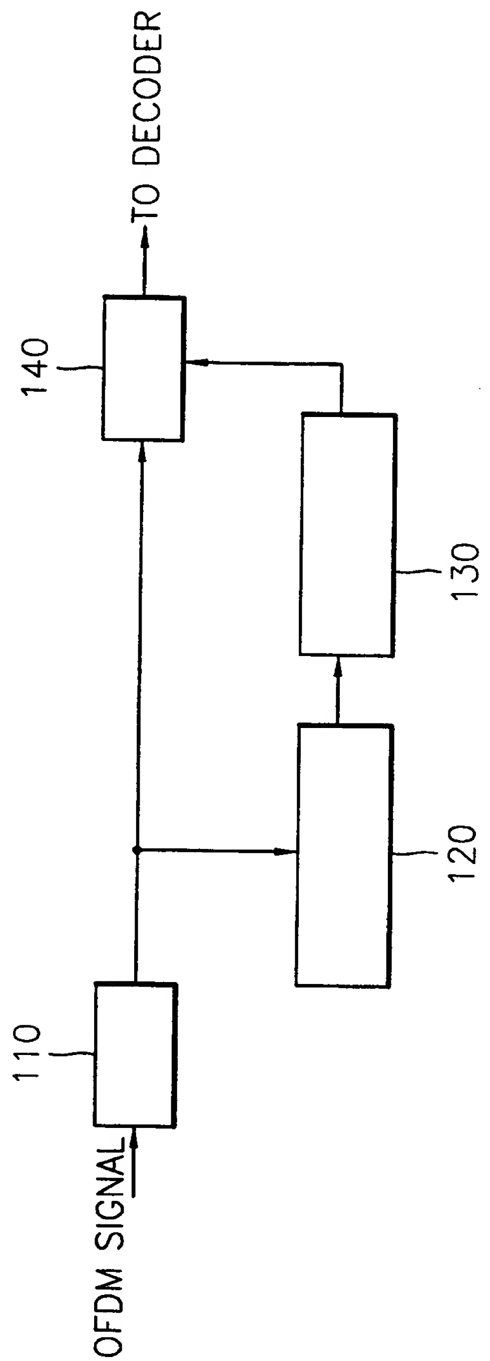


FIG. 2

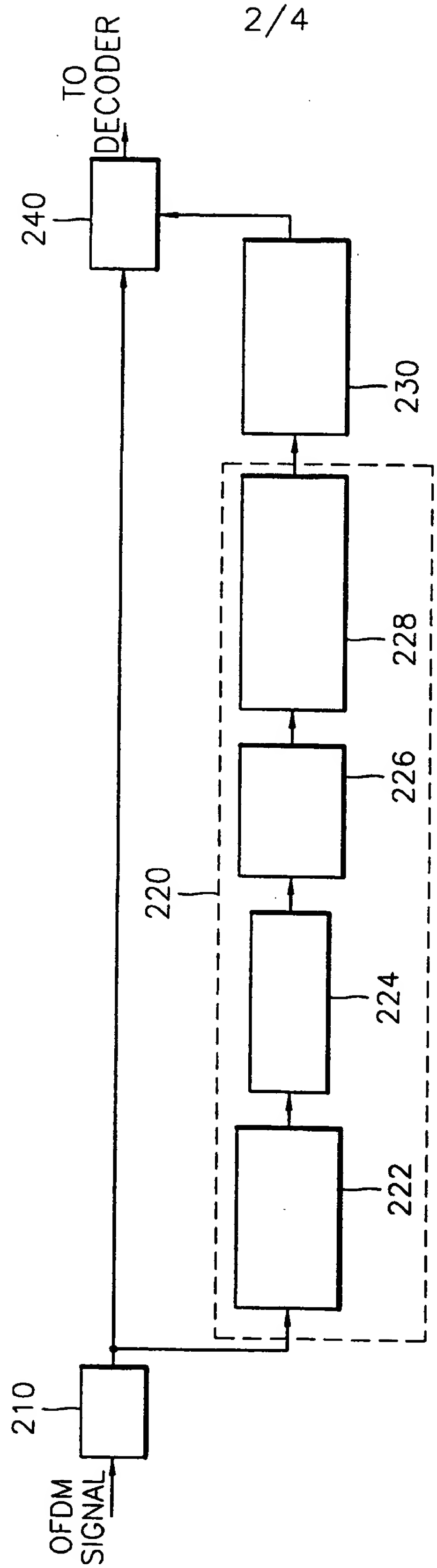


FIG. 3

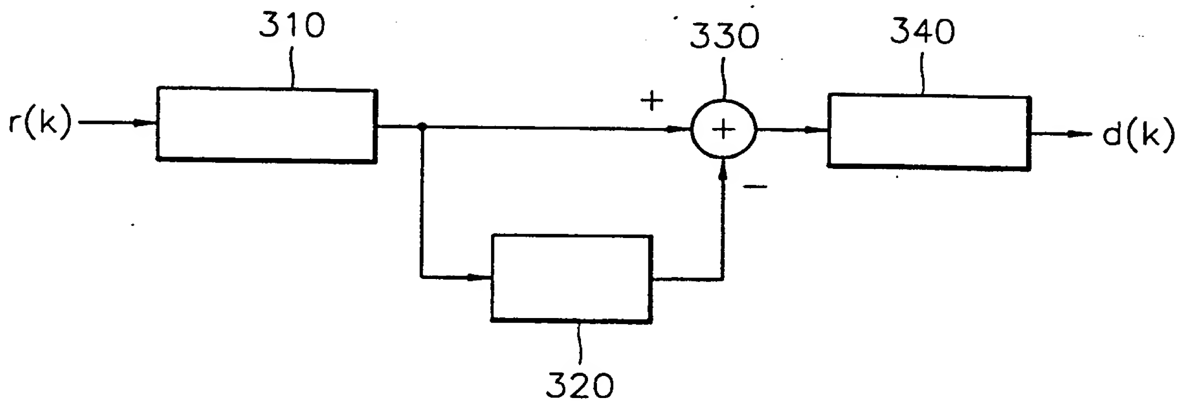


FIG. 4

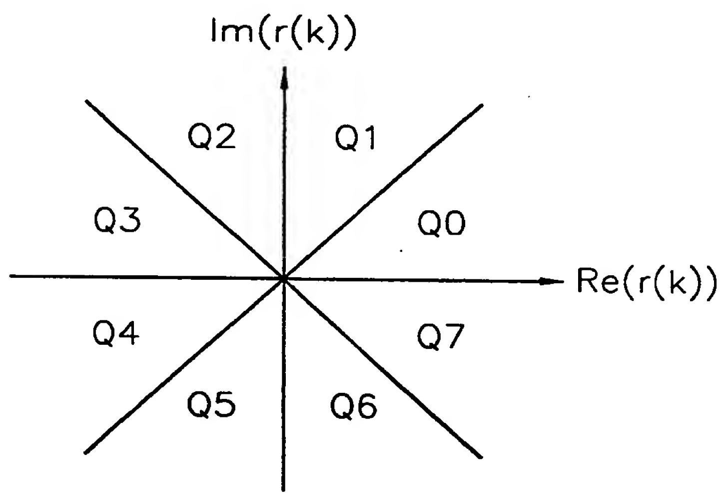


FIG. 5

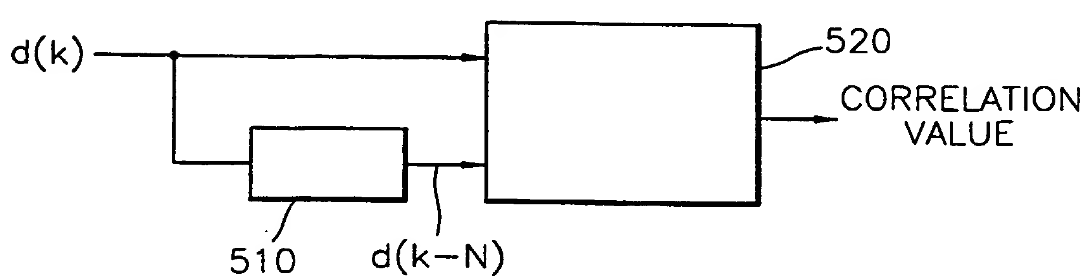
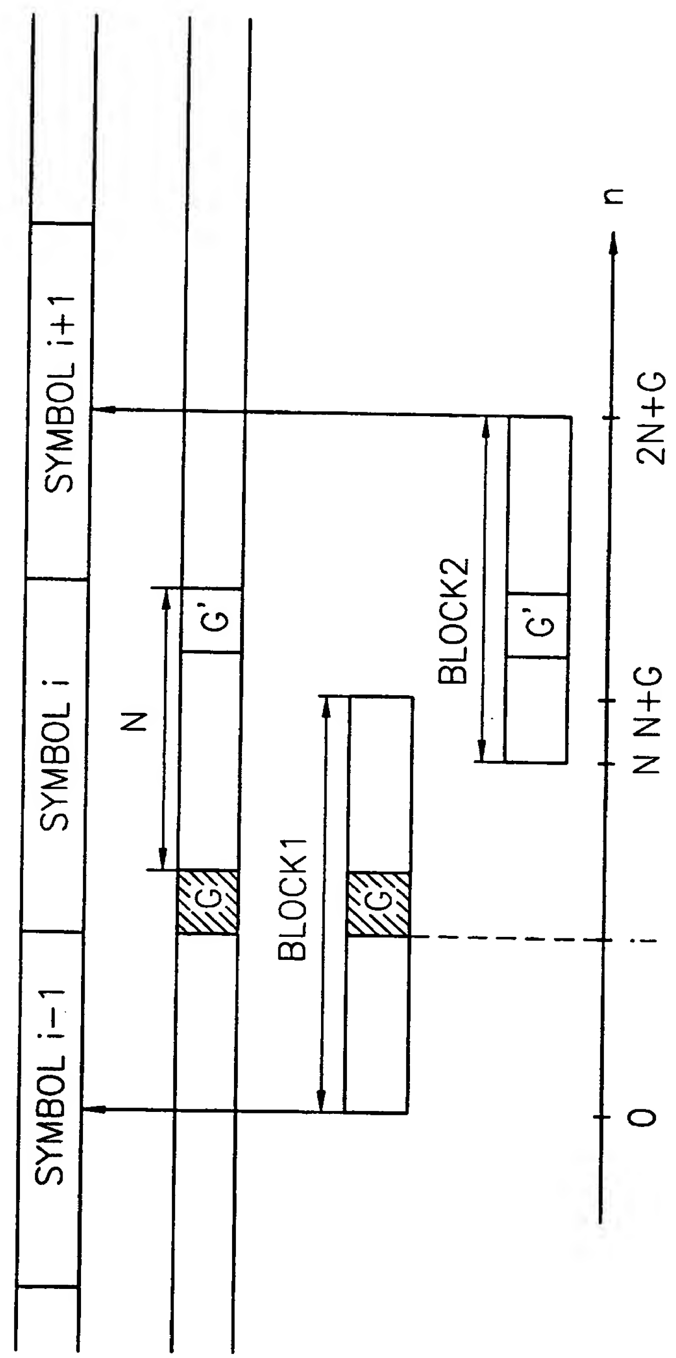


FIG. 6



INTERNATIONAL SEARCH REPORT

International application No.
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A. CLASSIFICATION OF SUBJECT MATTER	
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C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	EP 0 786 889 A1 (DEUTSCHE THOMSON-BRANDT GMBH) 30 July 1997 (30.07.97), page 4, lines 19-46; page 5, lines 18-46; page 6, line 7 - page 7, line 24; fig.1,2.	1,2
A	EP 0 730 357 A2 (TELIA AB) 04 September 1996 (04.09.96), abstract; page 2, line 5 - page 3, line 38; page 4, lines 5-51; fig.1-5.	1,2
A	WO 94/26 046 A1 (BRITISH BROADCASTING CORPORATION) 10 November 1994 (10.11.94), abstract; page 1, line 5 - page 7, line 9; fig.1-3.	1

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International application No.

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